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Experimental and numerical modal analyses of a historical masonry palace

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ABSTRACT

This study presents the determination of modal properties of a historical masonry palace built between 1861 and 1865 in Istanbul. Both an experimental and a numerical study have been performed. The experimental study was based on ambient vibration survey while numerical analysis was based on finite element analysis of the structure. The results of the experimental study were used to tune the numerical model of the structure. As the most doubtful parameter, the modulus of elasticity of the masonry was adjusted to achieve the experimental results with numerical model by simple operations. Obtaining good consistency between the experimental and numerical analysis, the study revealed the dynamic properties of the palace.

1. Introduction

This study was developed within the PROHITECH (Earthquake protection of historical structures by reversible mixed technologies) project [1] and aims to present the dynamic identification of Beylerbeyi Palace, constructed between 1861 and 1865 on the Asian shore of the Bosporus in Istanbul. Due to many uncertainties associated with the construction systems, material properties, modelling techniques, analysis methods and soil interactions, evaluation of a historical structure is indeed a difficult task. However, sophisticated measurement techniques on the real structure enable engineers to track the real behaviour of the structure and calibrate the numerical models to use in further assessments [2]. Because of the historical importance of Beylerbeyi Palace and the known difficulties, both experimental and numerical analyses were seen essential.

Modal properties of a structure can be experimentally determined by forced or ambient vibration tests using modal identification methods [3–7]. Ambient vibration survey has been preferred in this study because it works in natural conditions and no excitation is required, hence, the test implies a minimum interference with normal use of the structure. Furthermore, ambient vibration testing has recently become the main experimental method for assessing the dynamic behaviour of full-scale structures and it has generally been preferred for testing historic structures [8]. The obtained data are important but can provide more meaningful results if they are used to update a finite element model of the building, which is potentially able to estimate important mechanical properties [9–12].

In the numerical part of this study, a 3D finite element model, based on the geometric survey of the building, was developed. For the material properties laboratory based investigation was performed and required parameters for the masonry were determined [2]. In this laboratory based experimental investigation, test specimens were created by freshly prepared lime mortar and clay burnt brick since even non destructive tests were allowed by the authorities.

Under these conditions numerical model of the structure was updated based on the experimental modal data. The aim was to correct young modulus of the material in the initial FE model through a model tuning procedure to catch the same dynamic characteristics obtained by the experimental study. Before the experimental and the numerical part of the study, brief information about structural system of the palace would be useful to understand the performed analyses.

2. Beylerbeyi Palace

The three-storey main structure is consisted of a basement and two ordinary floors with a 72 m length along the shore (longitudinal direction) and 48 m in the perpendicular direction (transversal direction). The storey heights of the basement floor change between 1.5 and 2.5 m and that floor is partially underground while

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in the ordinary floors they vary between 7 m and 9 m. Fig. 1 shows a general view of the palace and the architectural plan lay-outs for the basement, first floor and second floor.

The structure is mainly made of masonry walls and timber slabs. On the basement floor the masonry walls are composed of stone and lime mortar. Thicknesses of the walls are changing between 2 m and 1 m and it is often 1.4 m on that floor. These walls are also forming the foundation system of the palace. On the other hand, brick and lime mortar were used on the first and second floor. The thickness of the walls in the first storey is generally 80 cm while it is 60 cm in the second floor. Cast iron clamps were also used within the walls to increase the out of plane stability of

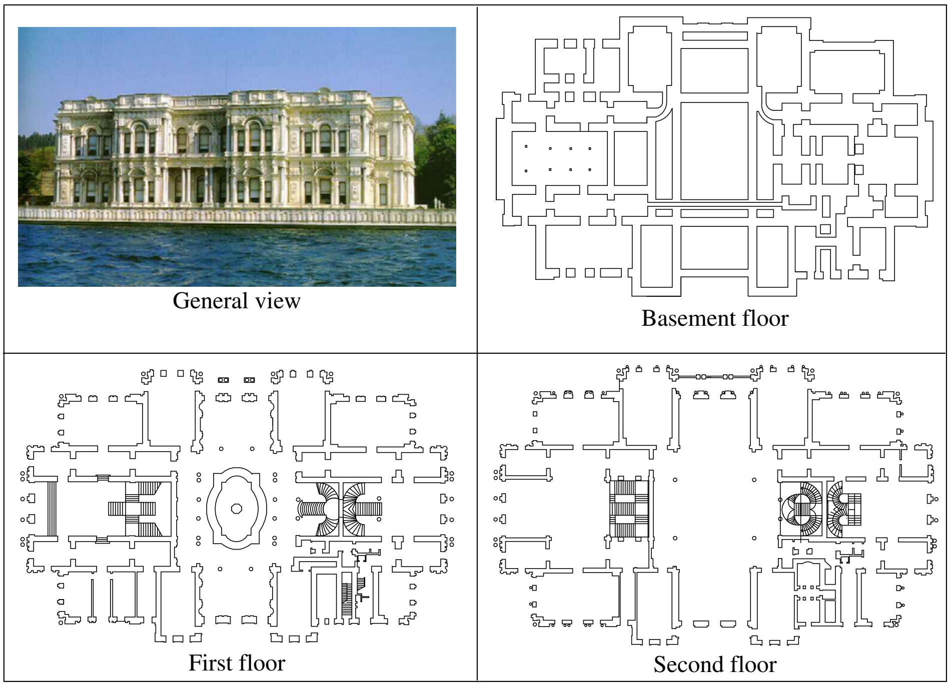

Fig. 1. Beylerbeyi Palace and the architectural plans of its floors.

Fig. 2. Structural walls and timber slab on the basement and the roof of the palace.

Fig. 3. Examples from the interior decoration of Beylerbeyi Palace.